

The University of Chicago

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A DISSERTATION SUBMITTED TO THE
FACULTY OF THE DIVISION OF THE
PHYSICAL SCIENCES IN CANDIDACY FOR
THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF PHYSICS

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Reprinted from
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Energy Distribution and Positive Excess of Mesotrons

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Energy measurements of penetrating cosmic rays have been made near sea level with a vertical cloud chamber placed in a magnetic field. The chamber expansions were controlled by a threefold coincidence Geiger-Müller counter system. One of the counters was shielded by 10.2 cm of lead and set beneath the chamber. The soft component was eliminated by absorption by the lead. Our energy spectrum in the region from 0.2 Bev (billion electron volts) to 2 Bev differs slightly from that obtained by Blackett without lead filter, although at higher energies they coincide. The correspondence between the experimental results and Euler's theoretical curve for the hard component is discussed. Throughout the measured energy range (0.2 Bev to 10 Bev) we find approximately 29 percent more positive mesotrons than negatives for each energy.

INTRODUCTION

THE total cosmic-ray energy spectrum, as found in a cloud chamber placed in a powerful magnetic field, has been measured by several experimenters.¹⁻⁵ We have made measurements on the hard cosmic-ray component alone in the energy range 0.2 Bev to 10 Bev (1 Bev = 10^9 electron volts).

The hard component was abstracted by absorbing the soft electron component in a lead block 10.2 cm thick. Such a block should not affect hard particles with energies greater than about 0.2 Bev, if one assumes that they are mesotrons which lose energy by ionization only. To check this assumption, a 1.27 cm lead plate, an optimum thickness for secondary shower production, was set on top of the cloud chamber. The small number of resulting multiple tracks confirms the hypothesis that the penetrating particles under investigation lose little energy except by ionization. By comparing our results with the energy spectrum of all components as observed by others, it is possible to separate the spectra of the soft and hard components.

APPARATUS⁶

The diaphragm type cloud chamber was 30 cm in diameter and 2.7 cm deep. It was filled with

argon and ethyl alcohol to an excess pressure of 350 g per square cm. This chamber was placed vertically in a magnetic field of 16,000 oersteds produced by a large electromagnet. Over the region of the chamber the magnetic field was uniform to within 15 percent. It required 132 kilowatts to maintain this field over a 19.2 cm air gap.

The expansions of the chamber were controlled by a threefold coincidence Geiger-Müller counter system,⁷ Fig. 1. Two tubes (30 cm $\times$ 2.5 cm

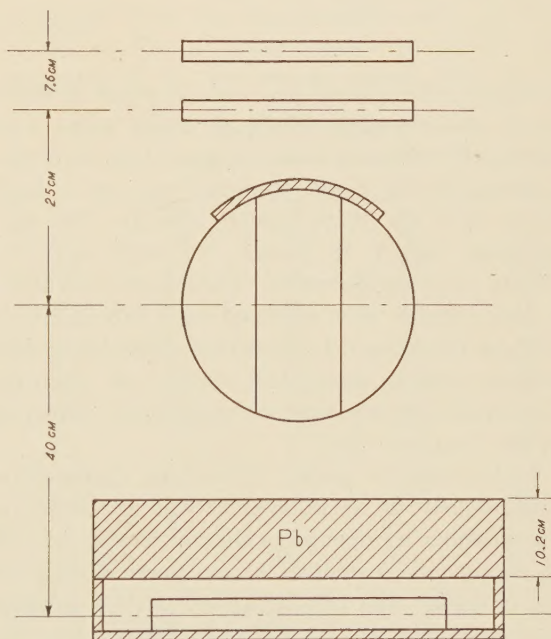


FIG. 1. Arrangement of counters and shields.

¹ P. Kunze, *Zeits. f. Physik* **80**, 559 (1933).

² C. D. Anderson and S. H. Neddermeyer, *Int. Conf. Physics, Lond.*, 171 (1934).

³ P. M. S. Blackett and R. B. Brode, *Proc. Roy. Soc. A* **154**, 573 (1936).

⁴ P. M. S. Blackett, *Proc. Roy. Soc. A* **159**, 1 (1937).

⁵ L. Leprince-Ringuet and J. Cussard, *J. de phys. et rad.* **8**, 207 (1937).

⁶ A more complete description of the apparatus is to be published elsewhere.

⁷ I am indebted to Mr. Francis Shonka for these tubes.

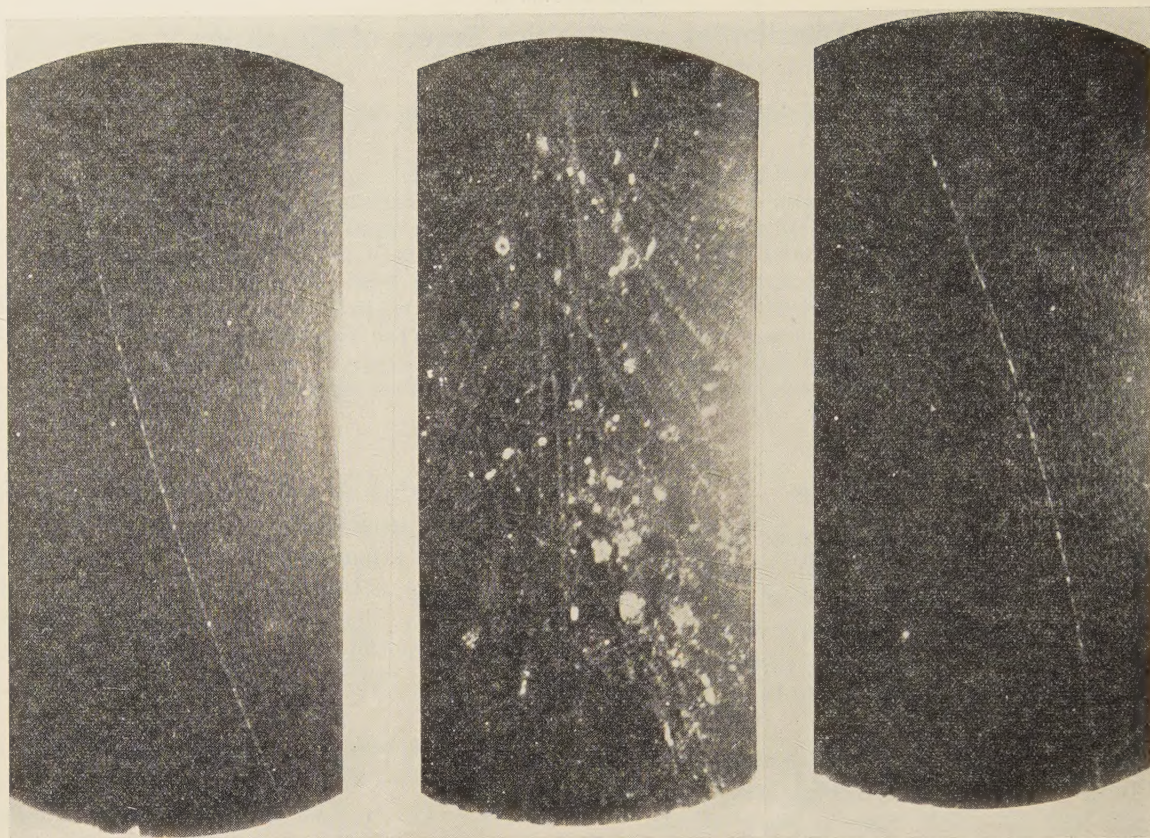


FIG. 2. Typical tracks.

diameter) were placed in a vertical plane directly above the chamber. Each of these tubes was electrically shielded with a copper box. Directly underneath the cloud chamber was set a lead block 10.2 cm thick which absorbs the soft radiation before it enters the third counter (38 cm $\times$ 4.1 cm diameter). The bottom and sides of this counter were enclosed by a box made of 1.27 cm thick lead. In threefold coincidence this counter system gave 0.54 counts per minute. This counting rate was not appreciably affected by the magnetic field.

Light from a Sperry carbon arc lamp (run continuously at 13 kilowatts) was admitted to the chamber by opening a shutter at the time of an expansion. A central 11 cm vertical strip of the chamber was photographed with a camera equipped with an $f:2.8$ Tessar 50-mm lens on 35-mm Agfa ultra-speed film. This film was projected to full size through a stereoscopically matched lens and the sagitta of the images of

curved tracks measured with a micrometer stage. The accuracy of this method was found to be about the same as that of measuring and plotting coordinates of points along a track using the original negative and a Geneva comparator.

THE ENERGY SPECTRUM

By reason of the magnetic field and the lead shielded G-M counter control of the cloud chamber, the large majority of our photographs show a single slightly curved track whose linear droplet density resembles that of a beta-ray. Shower pictures are rare and seldom seem to be associated with penetrating particles. Typical tracks are shown in Fig. 2. 923 tracks of this nature were measured giving the data for constructing their energy spectrum.

In order to set a limit to the precision to which energy measurements could be made, cosmic-ray tracks were photographed without the magnetic field to find the distortions. These were inter-

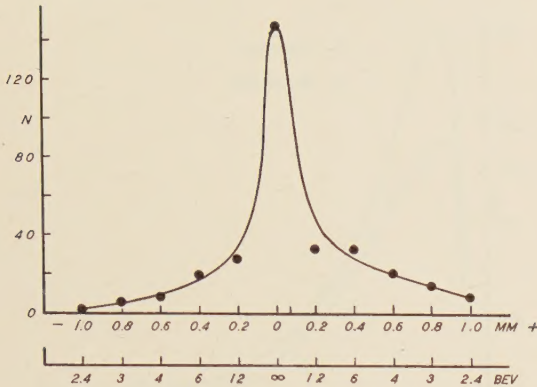


FIG. 3. Distribution of tracks when the magnetic field is zero. The sagittae of tracks (caused by distortions) are plotted as abscissae.

persed with the photographs taken with the magnetic field. Fig. 3 shows the distribution of tracks photographed with no magnetic field. Here the ordinates represent the number of tracks observed which have sagittae (for arc length of 20 cm) as given by the abscissae. The energy scale is that which would be indicated by such a curvature in a magnetic field of 16,000 oersteds. It is clear from this figure that a curvature corresponding to energies as great as 10 Bev are probably significant. 183 tracks were obtained with energies larger than this.

Table I gives the number of tracks in energy intervals. The number observed in the energy interval below 0.7 Bev is reduced by the lead absorbers and by the magnetic deflection of particles away from the counters. The remainder of the energy spectrum is in good agreement with that found by Blackett.⁴ This indicates that if any electrons exist with energies above 0.7 Bev at sea level, they must have nearly the same energy distribution as do the mesotrons. The data are plotted in the curve of Fig. 4, where the blocked area gives the same data for energy intervals of 0.1 Bev.

THEORETICAL COMPARISON

Figure 5 shows the data plotted on a double logarithmic scale. If ΔN is proportional to E^γ , as frequently assumed, the datum points should lie on a straight line. This is clearly contrary to fact. However, if one uses the formula of Euler,⁸ which

⁸ H. Euler and W. Heisenberg, *Ergeb. d. exakt. Natur-*

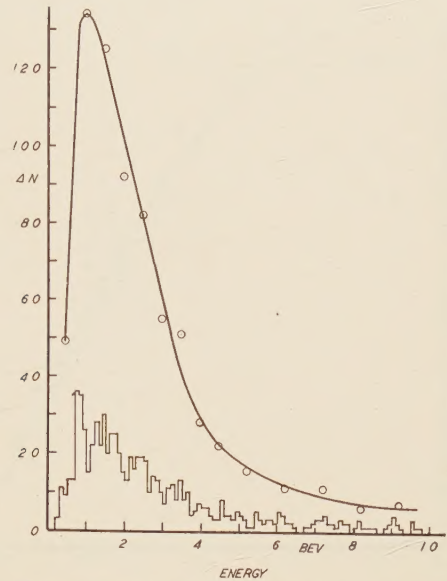


FIG. 4. Energy distribution of tracks. Energy intervals of 0.1 Bev are used.

assumes a power law distribution of mesotrons at high altitudes with subsequent loss of energy by ionization and diminution by spontaneous disintegration, a good fit is possible as shown by the curve of this figure. We should like to point out that an almost equally good fit can be obtained from an exponential curve, since as shown in Fig. 6, Euler's curve is not far from exponential in this energy range. Our experi-

TABLE I. Energy distribution of tracks.

E_1	E_2	$\Delta N(+)$	$\Delta N(-)$	ΔN_T
0.2	0.7	31	18	49
0.7	1.2	78	56	134
1.2	1.7	73	52	125
1.7	2.2	48	44	92
2.2	2.7	44	38	82
2.7	3.2	34	21	55
3.2	3.7	26	25	51
3.7	4.2	17	11	28
4.2	4.7	15	7	22
4.7	5.7	14	17	31
5.7	6.7	13	9	22
6.7	7.7	11	11	22
7.7	8.7	7	5	12
8.7	9.7	5	9	14
9.7	∞			184
Total		416	323	923

wiss. 17, 41 (1938), Eq. (50).

$$f(1000, p) = cJ_0\gamma \frac{(2 \times 10^9)^\gamma}{(pc + 900a)^{\gamma+1}} \left[\frac{pc}{10(pc + 900a)} \right]^{bc/pc + 1000a}$$

with $cJ_0 = 100$, for $\Delta E = 0.5$ Bev; $\gamma = 1.87$; $a = 2.0 \times 10^6$; $bc = 0.74 \times 10^9$.

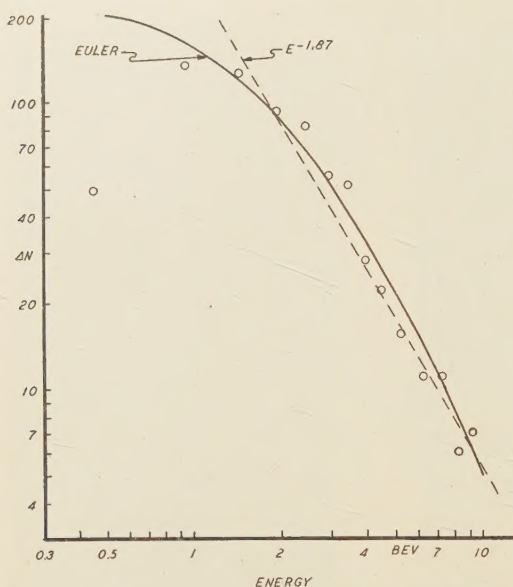
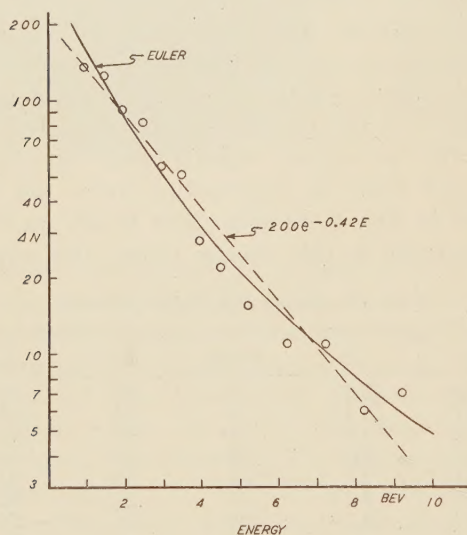


FIG. 5. Energy distribution on double logarithmic scale.

FIG. 6. Comparison of data with power law distribution (Euler) and exponential law ($200 \exp [-0.42E]$).

mental data are not adequate to decide definitely between these two.

THE POSITIVE EXCESS

Blackett and Brode³ reported an excess of high energy positives among the tracks over 10 Bev. Later⁴ Blackett felt that the excess was within experimental error. In these experiments no lead

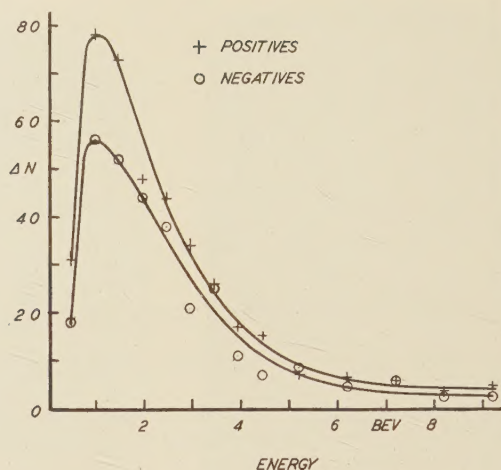
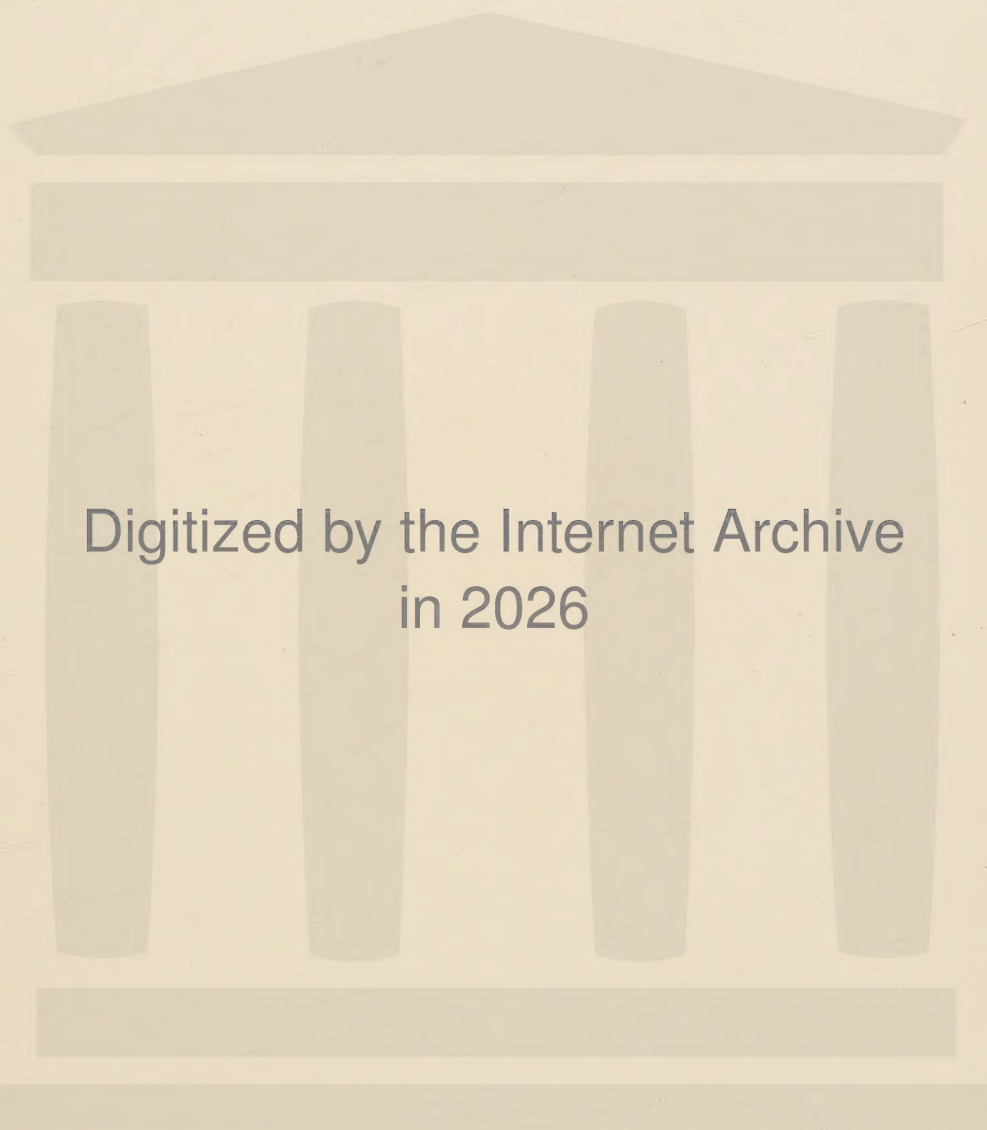


FIG. 7. Comparison of positives and negatives.

absorbers were used. LePrince-Ringuet, using a 14-cm lead absorber beneath his chamber, published results⁵ showing a ratio of positives to negatives of 1.7.

Figure 7 shows a comparison of the positives and negatives which we obtained. The ratio of positives to negatives for *each* energy fluctuates around the value 1.29 which is the ratio of the total number of positives to the total number of negatives. In order to make certain that the chamber was not distorting our results, we reversed the direction of the magnetic field for the last $\frac{1}{3}$ of our photographs. This reversal did not appreciably alter the positive excess. Thus it appears either that the introduction of the lead absorber enhances the positive excess by being more impervious to the negatives, or that there is an initial excess of positives. Since the ratio of positives to negatives remains nearly independent of the energy, the latter explanation seems to be more probable. We hope to make further studies reducing the thickness of the lead plate to determine the role of the absorber.

I wish to express my sincere thanks to Professor A. H. Compton for his invaluable advice and encouragement. In both the experimental work and the analysis of the results, Mr. Donald Hughes has worked continually with me, giving help without which the study could hardly have been completed. I wish also to thank Mr. Ralph Meagher and Mr. Winston Bostick for their assistance.



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